HCNG Heavy Duty Vehicle Prime Mover

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Objectives

- Develop a low-emissions heavy-duty vehicle engine repowering package that seamlessly replaces existing natural gas and diesel engines in today's buses and trucks.
- Exceed DOE's goal of reducing emissions by 75% compared to 1998 emission standards by achieving a 99.5% reduction. Corresponding emission levels of carbon monoxide (CO) will be <1 ppm; non-methane hydrocarbon (NMHC) emissions will be <0.05 g/hp-hr; and oxides of nitrogen (NO_x) will be <0.15 g/hp-hr.
- Maintain or enhance current vehicle driveability by effective selection, matching, and configuring of off-the-shelf components.
- Meet DOE's requirement to maintain thermal efficiency by obtaining an overall thermal efficiency of greater than 35%.
- Prove and enhance the engine design through in-service testing.
- Develop a public/private partnership to implement a commercialization plan that will bring new business and economic opportunities to Nevada.

Technical Barriers

This project addresses the following technical barrier from the Technology Validation section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year R,D&D Plan:

- A. Vehicles

Approach

- Use hydrogen added to natural gas (HCNG) to achieve high charge dilution ratios to create near-zero NO_x emissions.
- Incorporate an alternative engine design from that of current heavy-duty engines. Engine design features include:
  - Nickel silicon carbide cylinder bores
  - Quiescent combustion
  - Higher rpm operation
  - Larger displacement
  - Mass air flow engine control

Accomplishments

- Demonstrated 0.14 g/hp-hr simulated driving cycle NO_x emissions.
- Produced equivalent power and torque to natural gas engine.
- Demonstrated 38% engine efficiency.
- Bus is currently operating in Las Vegas.

Future Directions

- Expand the work to convert five additional City of Las Vegas buses to HCNG.
- Market HCNG hydrogen technology to other transit districts.

Introduction

The use of hydrogen as a fuel additive to extend the lean burn limit of conventional fuels has been repeatedly demonstrated to be a viable approach to achieving near-zero exhaust emissions from internal combustion engines. This technology is intended to be a near-term application for hydrogen and to accelerate hydrogen infrastructure development given the current economic climate. Hydrogen fuel-related problems such as high fuel cost, high prime mover costs (fuel cells) and low energy density are largely overcome by supplementing an existing, higher energy storage density, lower-cost fuel, such as natural gas, and implementing a low-cost prime mover such as internal combustion engines.

Demonstrating that this low-cost hydrogen technology can improve emissions of oxides of nitrogen by a factor of thirty over current generation natural gas engines can create the incentive by which a hydrogen infrastructure can be developed that will be necessary for the successful implementation of fuel cells.

Approach

Collier Technologies, LLC is using charge dilution as the mechanism for controlling harmful exhaust emissions. The basic technique employed is to combine exhaust gas recirculation (EGR) and lean burn. Cooled and dried EGR is used to control NO_x emissions and lean burn to control CO and NMHC emissions. It is anticipated that lean burn will achieve approximately 2 to 4% oxygen in the exhaust. This will allow an off-the-shelf oxidizing catalyst to achieve very high conversion rates for both CO and NMHC emissions. Because the exhaust gas temperatures will be comparatively very low (<1000°F), catalyst lifetime should be extremely high (>100,000 miles).

To achieve near-zero NO_x emissions (10 to 20 ppm) using charge dilution, the engine must operate with an overall lambda (air-fuel ratio divided by the stoichiometric air-fuel ratio, including EGR) of between 1.8 and 2.0. To achieve this value, at least 30%, by volume, of the fuel must be hydrogen. Any less than that will not support sufficiently consistent combustion from cylinder to cylinder or from cycle to cycle. Any attempts to achieve this through mechanical means (high turbulence combustion chambers, etc.) will result in loss of engine efficiency through increased combustion chamber heat transfer rates and increased NO_x emissions compared to “quiescent” or open combustion chambers and hydrogen addition to the fuel. The result is that mechanical enhancement (swirl, tumble, etc.) for lean burn will require higher values of lambda to achieve equivalent NO_x emissions to that achieved by hydrogen as a fuel enhancement.

Results

A 30-ft transit bus was purchased by DOE and shipped to Collier Technologies (then called NRG Tech) for conversion to HCNG operation. This bus came equipped with a Cummins 8.3L natural gas engine. The project called for characterizing the exhaust emissions from the current configuration so that the benefits of HCNG can be quantitatively assessed. Baseline exhaust emissions were taken from the engine using a steady state emissions test protocol that is designed to simulate the heavy-duty driving test procedure. This protocol is as follows:

Engine rpm at maximum torque value

Test Point 1100% loadEmissions are 15% of final value

Test Point 275% loadEmissions are 15% of final value

Test Point 350% loadEmissions are 15% of final value

Test Point 410% loadEmissions are 10% of final value

Engine rpm at maximum power value

Test Point 5100% powerEmissions are 10% of final value

Test Point 675% powerEmissions are 10% of final value

Test Point 750% powerEmissions are 10% of final value

Test Point 8IdleEmissions are 15% of final value

The results of testing the Cummins engine that was installed in this bus using the protocol listed above are shown in Table 1.

Emissions results for the 8.8L Collier Technologies engine using the same testing protocol and using a 30/70 mixture of hydrogen and natural gas are shown in Table 2.

Table 1. 8-Mode Steady State Emissions Summary
Cummins 8.3L Natural Gas Engine (as received)

Individual Modes		NO_x g/hp-hr	THC g/hp-hr	NMHC (g/hp-hr)	CO g/hp-hr	Weighting Factor
1400 rpm	- 100% Load	7.42	5.21	0.16	0.19	0.15
	- 75% Load	4.70	2.57	0.08	0.22	0.15
	- 50% Load	5.67	3.37	0.10	0.25	0.15
	- 10% Load	5.77	7.70	0.23	0.59	0.10
2400 rpm	- 100% Load	1.18	2.82	0.08	0.28	0.10
	- 75% Load	0.80	4.26	0.13	0.32	0.10
	- 50% Load	0.44	5.56	0.17	0.37	0.10
800 rpm	- Idle	6.96	107.74	3.23	12.98	0.15
Weighted 8 Mode (g/hp-hr)		4.60	19.87	0.58	2.20	
Weighted 8 Mode (g/kw-hr)		6.16	26.63	0.78	2.95	

Table 2. 8-Mode Steady State Emissions Summary
HCNG Bus Engine

Individual Modes		NO_x g/hp-hr	THC g/hp-hr	NMHC (g/hp-hr)	CO g/hp-hr	Weighting Factor
1800 rpm	- 100% Load	0.15	3.70	0.11	0.00	0.15
	- 75% Load	0.12	3.86	0.12	0.00	0.15
	- 50% Load	0.09	4.86	0.15	0.00	0.15
	- 10% Load	0.13	8.82	0.26	0.00	0.10
2800 rpm	- 100% Load	0.21	3.31	0.10	0.00	0.10
	- 75% Load	0.15	3.77	0.11	0.00	0.10
	- 50% Load	0.10	5.75	0.17	0.00	0.10
800 rpm	- Idle	0.22	7.21	0.22	0.00	0.15
Weighted 8 Mode (g/hp-hr)		0.15	5.11	0.15	0.00	
Weighted 8 Mode (g/kw-hr)		0.20	6.85	0.21	0.00	

Conclusions

Emissions, power, torque, and efficiency goals have been met with our project methodology. NO_x emissions have been reduced by a factor of 30 when compared to the existing engine without a loss of power, torque characteristics or fuel efficiency. Major milestones for the remainder of the project will be to demonstrate drivability in an operating bus and verify exhaust emissions in a driving test.